Electrical Measurements

Code: EPM1202

Lecture: 4 **Tutorial: 2** **Total: 6**

Dr. Ahmed Mohamed Azmy

Department of Electrical Power and Machine Engineering

Tanta University - Egypt

Faculty of Engineering

Tanta University

This course aims at providing the basic knowledge in order to:

- Enhance skills about basis of <u>electromechanical instruments</u> and their <u>dynamics</u> including the difference between dc and ac instruments
- Help students to deal with <u>ac and dc bridges</u> for measuring electrical quantities
- Encourage the utilization of different types of <u>transducers</u> with electrical measuring instruments
- Develop the principles of <u>oscilloscope</u> and its use to measure voltages of electrical signals
- Help in recognizing <u>different types of errors</u> caused by using electrical measurement devices

Intended Learning Outcomes (ILOs)

Knowledge and Understanding

a1- State the main features and utilizations of different types of electrical measuring instruments.

a2- List the principles of operations of moving coil instruments and their applications in dc and ac measurements

a3- Mention the principles of operations of moving iron instruments and their applications in ac and dc measurements

a4- State the principles of operations of electro-dynamic and electrostatic instruments and their applications in ac and dc measurements.

a5- Say the mechanisms of transducers and their applications

Intended Learning Outcomes (ILOs)

Intellectual Skills

b1- Develop the mathematical formulas to describe the dynamic response of measuring instruments.

b2- Evaluate the advantages and the disadvantages of using moving coil in both ac and dc measurements.

b3- Derive the equivalent electric circuit associated with different electromechanical instruments.

b4- Modify electro-dynamic instruments to measure power and power factor.

b5- Extract the mathematical formulas that used to describe the transducers to measure non-electrical quantities.

Intended Learning Outcomes (ILOs)

Professional and Practical Skills

c1- Choose and locate suitable instruments to completely measure electrical quantities in different electrical sketched circuits

c2- Plan for minimizing the number of instruments to measure the required electrical quantities in different electrical circuits.

c3- Build up electrical bridges to measure resistance and inductance.

c4- Measure the reading of electrical circuits to evaluate errors caused by inserting electrical measurement devices into electrical circuits.

Intended Learning Outcomes (ILOs)

General and Transferable Skills

d1- Cooperate to collect information about certain topics

d2- Report a main subject through defined groups

d3- Build self confidence

Weighting of Assessments (100)

Quizzes	2 %
Lab. Reports	7.5 %
Problem solving	8 %
Mid-Term Examination	10 %
Final Lab. Exam.	12 .5 %
Final-term Examination	60 %
Total	100 %

References

- AK. Sawhney, “A Course in Electrical and electronics Measurement and Instrumentation” Dhanpat Rai and Co Pvt. Ltd., New Delhi 2004
- B.A. Gregory, An Introduction to Electrical Instrumentation and Measurement Systems”, English Language Book Society and MacMillan, Second Edition, 1981

Units and dimensions

Normally, the International system of units, usually abbreviated to “SI” units, is used for this purpose

Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Luminous intensity	Candela	cd
Amount of substance	Mole	mol

It is possible to derive SI units from combinations of basic units

- **Velocity: metres per second (m/s)**
- **Acceleration : metres per second squared (m/s^2)**

Common multiples

Prefix	Name	Meaning	
M	mega	multiply by 1000000	(i.e. x 10^6)
k	kilo	multiply by 1000	(i.e. x10^3)
m	milli	divide by 1000	(i.e. x 10^{-3})
μ	micro	divide by 1000000	(i.e. x 10^{-6})
n	nano	divide by 1000000000	(i.e. x 10^{-9})
P	pico	divide by 1000000000000	(i.e. x 10^{-12})

Charge

Unit → coulomb (C)

One coulomb is equivalent to one ampere second

1 coulomb = 6.24 x 10^{18} electrons

The ***coulomb*** is a unit of electrical charge defined as ***the amount of charge transferred by a current of one ampere in one second***

$$Q = I \cdot t \quad \text{“C”}$$

Force

Unit → Newton (N)

One Newton is equivalent to kilogram metre per second squared

The Newton is defined as the force, which causes an acceleration of one metre per second squared when applied to a mass of one kilogram

$$\text{Force } (F) = \text{m . a}$$

Where "m" is the mass in kilograms and "a" is the acceleration in metres per second squared

Work

Unit → joule (J)

One joule is equivalent to one Newton metre

The joule is defined as the work done when a force of one Newton is applied through a distance of one metre in the direction of force

$$W = F \cdot s$$

Where: “W” is the work done on a body in joules, “F” is the force in Newton and “s” is the distance in metres moved by the body in the direction of the force

Power

Unit → Watt (W)

One watt is one joule per second

The power is defined as the rate of doing work or transferring energy

$$P = W / t$$

Where: "P" is power in watts, "W" is the work done in joules and "t" is the time in seconds

Electrical potential

Unit → Volt (V)

One volt is equivalent to one joule per coulomb

One volt is the potential difference between two points in a conductor carrying a current of one ampere and dissipates a power of one watt

$$V = \frac{watt}{ampere} = \frac{joules/s}{ampere} = \frac{joules}{ampere.s} = \frac{joules}{coulombs}$$

Resistance

Unit → ohm (Ω)

one ohm is equivalent to one volt per ampere

It is defined as the resistance between two points in a conductor when a constant electric potential of one volt applied at the two points produces a current flow of one ampere in the conductor

$$R = \frac{V}{I} \qquad \Omega$$

Fundamentals of Measurements

Measurement is the process of experimentally obtaining information about magnitude of a quantity

The magnitude of quantities can be indicated by the position of a pointer moving over a graduated scale in the analogue instruments

It is also possible to indicate the value in the form of a decimal number in digital instruments

Basic definitions

Measuring Instrument

Measuring Instrument is a device that makes possible direct reading of values of a quantity being measured

It is a device used to measure, test, or examine parts in order to determine values with required specifications

Basic definitions

Measuring Instrument

The measuring instrument is used to perform one of the following functions:

- Indication
- Record
- Control

Basic definitions

Measuring Instrument

Instrument functions

- **Indication**: To measure and indicate the unknown value with the suitable display method
- **Record**: To measure and record the unknown value for further utilization
- **Control**: The device is equipped with a control system to regulate a certain process

Basic definitions

Measurement range

For any measuring device, the measurement range is the **maximum** value of the quantity, which can be measured

True value

It is the **actual** value of the variable that can be obtained without any errors

Basic definitions

- **Nominal value**

It is the standard value of the variable as given by the **manufacturer** under standard conditions

- **Calibration**

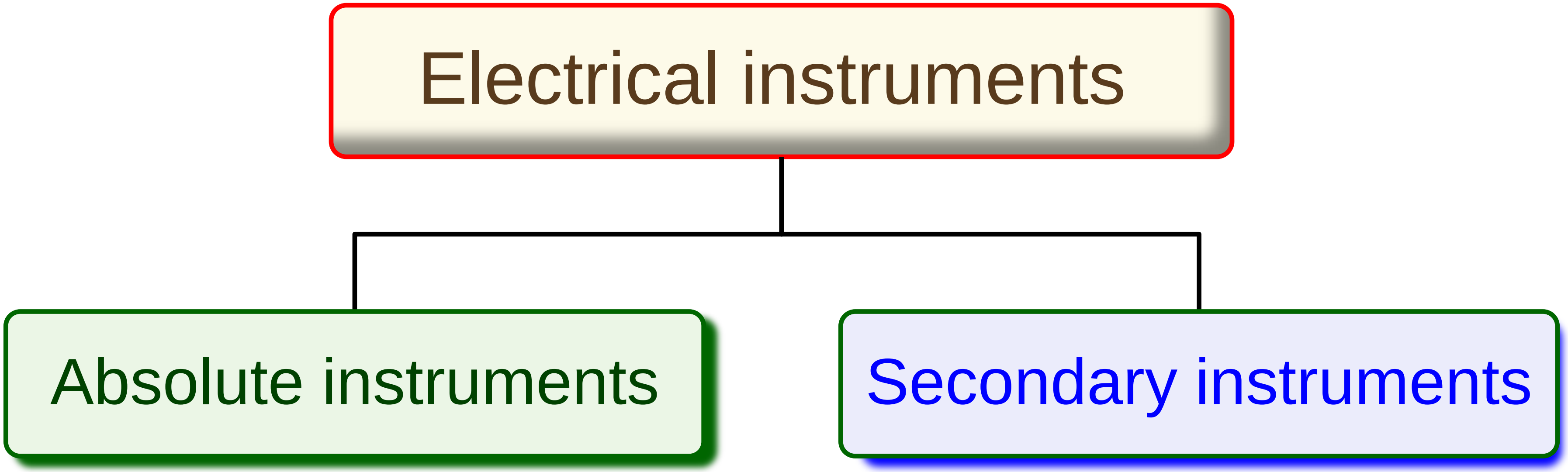
The calibration procedure is used to test the accuracy of measuring instruments

It is an *operation to create the relationship between quantity values provided by measurement standards and the corresponding indications of measuring system,* carried out under specified conditions and including evaluation of measurement uncertainty

Basic definitions

Calibration (cont.)

to perform the calibration process, absolute instruments are used, which are characterized by high accuracy and high prices



Basic definitions

Measurement error

The measurement error is the difference between the measured value and the true value

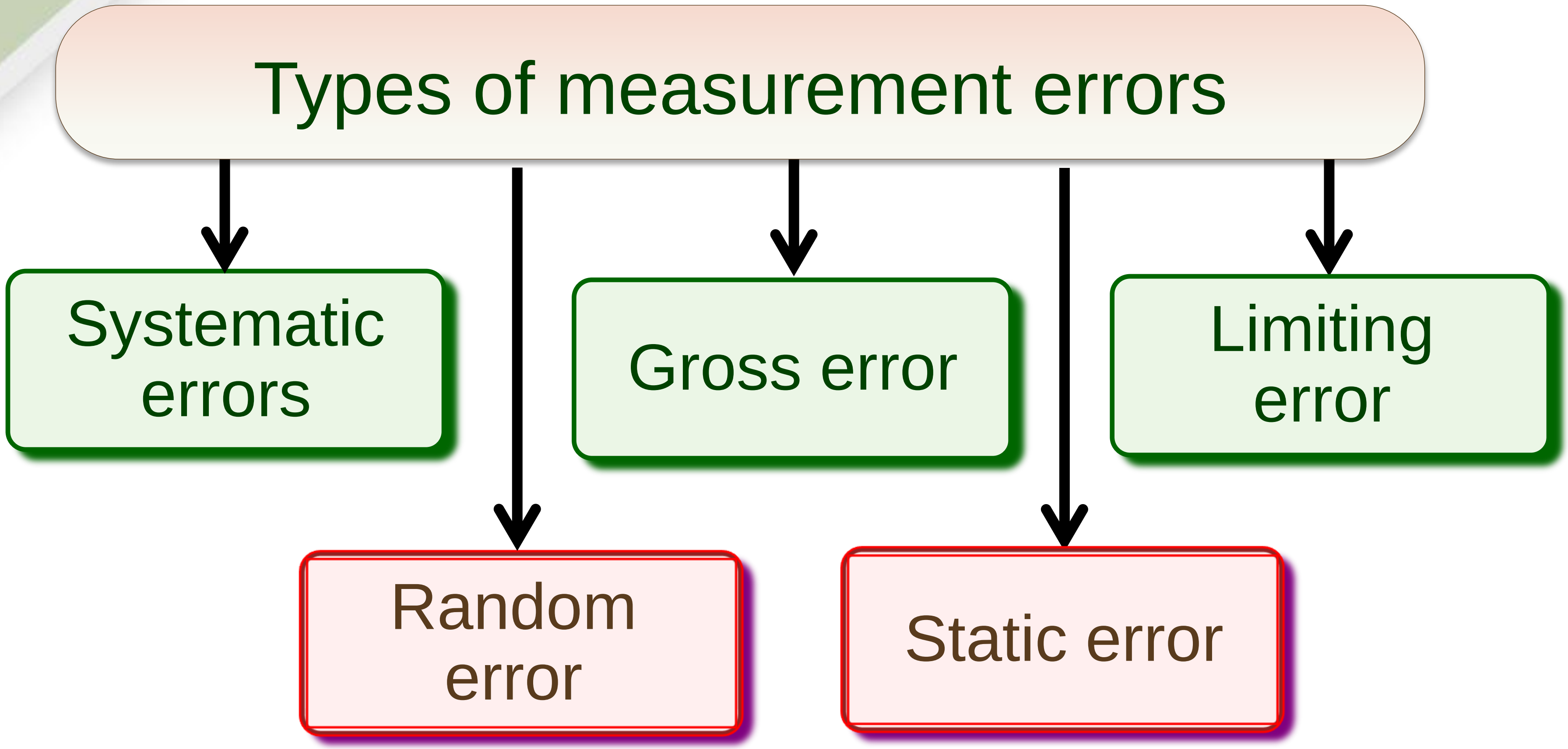
Large error means misleading values that can affect the decision-making

There are many reasons for the measurement errors

To compensate the measurement error, the reason of this error has to be defined

Basic definitions

Measurement error



Basic definitions

Systematic Errors

Appear always from measurement to measurement

Examples of causes are: DC offsets, gain errors, non-linearity... etc

If the instrument has a reading before connections, all subsequent measurements will be off by that amount

Tend to be either positive or negative every time and are considered to be bias in measurement

Can easily be compensated by proper zeroing and calibration of the measuring instrument

Basic definitions

Random error

Found in all analog and mixed-signal instruments

Caused by factors that randomly affect measurement

Does not have any consistent effects across the entire sample

Pushes observed scores up or down randomly

Can be considered as noise

Causes can be: building vibrations, electrical fluctuations, motions of the air, and friction in any moving parts of the instrument

They are difficult to be eliminated

Basic definitions

Gross error

Appears due to user or human mistakes in using the instrument, recording data or calculating data or the improper choice of the instrument

The presence of gross errors in measurements tends to bias the estimated state of the system

Using a wattmeter to measure low power factor load, may lead to error

Some people memorize string of data and then write down it collectively, which may induce error in data

To overcome these errors, measurement has to be carried out with great care and more than one reading has to be taken

Basic definitions

Limiting error

In most indicating instruments, the accuracy is guaranteed to a certain percentage of full-scale reading

The limits of these deviations from the specified values are known as limiting errors or guarantee errors

The limiting error has the smallest value at full scale and its value increases with readings lower than the full-scale values

Basic definitions

Static error

Static error is the difference between the measured magnitude and the true value given either as an absolute error or as relative error

$$\delta_o = \delta A = A_m - A_t$$

$$\delta_r = \delta_o / A_t = (A_m - A_t) / A_t$$

$$A_t = A_m / (1 + \delta_r)$$

Where: $\delta_o = \delta A$ is the absolute static error, δ_r is the relative static error, A_m is the measured value and A_t is the true value

Basic definitions

Static error

To compensate for the static error, the static correction is applied to modify the reading

The static correction is given as:

Static correction = $-\ \delta_o = -\ \delta A$

Example: An instrument is used to read a voltage of 120V, where the reading was 119.4V. Calculate the static error and the static correction for the instrument.

Solution:

$$\text{Static error: } \delta_o = \delta A = A_m - A_t$$

$$= 119.4 - 120 = -0.6 \text{ V}$$

$$\text{Static correction} = -\delta_o = -\delta A = 0.6\text{V}$$

Example: The limiting error of a 400V voltmeter is ± 1.5% at full scale. Calculate the limiting error when voltages of 200, 150 and 100V are to be measured.

Solution:

Limiting error = 400 * 1.5/100 = 6V

For 200V, the limiting error =6/200*100 = 3%

For 150V, the limiting error =6/150*100 = 4%

For 100V, the limiting error =6/100*100 = 6%

Basic definitions

Sensitivity

The minimum value of the measured quantity (input signal) necessary to obtain output signal

The smaller this value is, the larger the sensitivity

Sensitivity can be increased using suitable arrangements such as increasing the number of turns of a coil that used in measuring flowing current

The sensitivity can be measured using one of the following two expressions:

S = magnitude of input / magnitude of output

S = 1 / full-scale deflection

Basic definitions

Resolution

The resolution of a measuring device specifies the smallest value of the measured quantity (input signal), which could be possibly detected or indicated

It can be defined as the smallest variation in the measured value to which the instrument will respond

For example, if the instrument will not respond to currents lower than 0.05 A, the resolution of the instrument is 0.05

Basic definitions

Accuracy of measurement

The degree of closeness of measurements of a quantity to its actual or true value

The accuracy is related to the relative static error with the relation:

$$A = 1 - \text{relative static error} = 1 - \delta_r$$

The percent accuracy is given as:

$$a = 100 – \text{percent relative static error}$$

$$= 100 - 100\ \delta_r = 100\ (1 - \delta_r) = 100 * A$$

Basic definitions

Precision "reproducibility or repeatability"

A measure of the degree to which repeated measurements agree when obtained by the same method and under the same conditions

It is independent on the accuracy of the instrument

Instruments can be precise but inaccurate and vice versa

With systematic errors, precision can be increased by increasing sample size without improving the accuracy

Eliminating the systematic error will improve the accuracy but will not change the precision

Accuracy is determined by one measurement, while precision is determined with multiple measurements

Basic definitions

Tolerance

An indication of the uncertainty related to the measured value expressed in the same units of the measured value

If a resistance is given as: 1000 Ω ± 0.3 Ω

The resistance has a nominal value of 1000 Ω

The tolerance is ± 0.3 Ω

The true value is between 1000 - 0.3 and 1000 + 0.3

R is between = 999.7 Ω and 1000.3 Ω.

Basic definitions

Instrument efficiency

The ratio between the full scale and the consumed power during reading full scale

For the voltmeter:

$$\eta = \frac{V_{fs}}{P_{fs}} = \frac{V_{fs}}{\mathrm{V}_{\mathrm{fs}}^{2}/\mathrm{R}_{\mathrm{m}}} = \frac{\mathrm{R}_{\mathrm{m}}}{V_{fs}}$$

Where: R_m is the meter resistance
V_{fs} is the full-scale reading
P_{fs} is the consumed power at full scale

The voltmeter efficiency increases with the increase of its internal resistance

Basic definitions

Instrument efficiency

For an ammeters, the full-scale reading is assumed to be I_{fs} and the internal resistance is R_m

$$\eta = \frac{I_{fs}}{P_{fs}} = \frac{I_{fs}}{I_{fs}^2 R_m} = \frac{1}{I_{fs} R_m} \qquad \text{volt}^{-1}$$

The ammeter efficiency increases with the decrease of its internal resistance

Example: A measuring instrument has a full scale of 500V and an error of ± 1.0%. Calculate the instrument accuracy and percent accuracy. What is the percentage accuracy if the instrument is used to read: 250V and 100V

Solution: $\delta_r = 0.01 = \delta_o / A_t = \delta_o / 500$

$\delta_o = \pm 0.01 * 500 = \pm 5V$

$A = 1 - \delta_r = 1 - 0.01 = 0.99$

The percent accuracy:

a = 100 – percent relative static error = 100-1.0 = 99%

Solution (cont.):

$\delta_o = \pm 0.01 * 500 = \pm 5V$

$A = 1 - \delta_r = 1 - 0.01 = 0.99$

The percent accuracy:

a = 100 – percent relative static error = 100-1.0 = 99%

At 250V reading

Reading $= A_m = A_t + \delta_o = 250 \pm 5 = 245$ V or 255 V

$\delta_r = \delta_o / A_t = 5 / 250 * 100 = 2\%$

$a = 100 \pm 2 = 98\%$ or 102 %

At 100V reading

Reading $= A_m = A_t + \delta_o = 100 \pm 5 = 95$ V 0r 105 V

$\delta_r = \delta_o / A_t = 5 / 100 * 100 = 5\%$

$a = 100 \pm 5 = 95\%$ or 105 %

Example:

In a certain experiment, the measured resistance was 3456 Ω. The used resistor box contains the following resistors: 10 of 1000 Ω, ±0.1% 10 of 100 Ω, ±0.2%

10 of 10 Ω, ±0.4% 10 of 1 Ω, ±0.6%

Calculate the percentage uncertainty in the reading

Solution:

The error in measurement is:

3000*(0.1/100)+400*(0.2/100)+50*(0.4/100)+6*(0.6/100)

= 3 +0.8 + 0.2 + 0.036 =4.036 Ω

The percentage uncertainty = ±4.036 / 3456 * 100

= 0.1168%

Example:

During a measurement of a current, a change of 2 A causes a deflection of 3mm on the ammeter scale. Calculate the Ammeter sensitivity.

Solution:

The sensitivity is given as:

S = magnitude of input / magnitude of output

$$= 2 / 3 = 0.6667 \text{ A/mm}$$